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U.S. ARMY TARADCOM

ULTRASONIC LUBRICATION

OCTOBER 1977

by S. B. CATALANO

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U.S. ARMY TANK-AUTOMOTIVE
RESEARCH AND DEVELOPMENT COMMAND
Warren, Michigan 48090

TECHNICAL REPORT NUMBER 12351

ULTRASONIC LUBRICATION

BY

S. B. CATALANO

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TACTICAL VEHICLE COMPONENTS FUNCTION

ABSTRACT

This effort has produced a state-of-the-art survey. It involved literature search, conference attendance and meetings with workers and leaders in the fields of ultrasonic lubrication and adiabatic engines. It appears premature at this time to try to utilize ultrasonic lubrication in the combustion chamber of the adiabatic engine. However, this work includes two suggested adiabatic design changes which could be used if the need for ultrasonic lubrication of the combustion chamber of the adiabatic engine becomes sufficiently urgent.

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INTRODUCTION AND OBJECTIVE

The Propulsion Systems Division of TARADCOM's Research and Development Laboratory jointly with the Cummins Engine Company, is conducting a research program on the feasibility of military use of an adiabatic diesel engine. The aim of the adiabatic engine concept is to develop an engine that has very little, if any, heat losses, whereby cooling of the engine would not be required and a 30% improvement in fuel economy may be anticipated. To achieve these goals it has been necessary to resort to insulated pistons, cylinders, cylinder head and exhaust ports; this in turn results in higher engine operating temperatures and leads to the use of ceramic engine parts (e.g. ceramic piston cap and ceramic exhaust port). The adiabatic engine program began in 1974. To date, a single cylinder prototype engine using a ceramic piston was operated successfully for 160 hours. This achievement has been viewed with considerable optimism; however, further development of critical engine components is required in order to increase successful operating time.

Among the problems being faced by this high-risk, high-payoff engine is the problem of lubrication. Conventional lubricants break down at the adiabatic engine operating temperature.

The work reported here addresses the problem of lubricating the adiabatic engine. The technique investigated for this purpose is a major departure from conventional lubrication in the sense that it uses ultrasonics to maintain a space/cavity (cavitation)/separation between the bearing surfaces. This technique was originated by Dr. Beno Sternlicht of Mechanical Technology, Inc., Latham, NY. A bearing utilizing this technique is referred to as a squeeze-film bearing. Its design is a take-off on air bearings and is an ideal solution for applications where a supply of pressurized gas is not available or alternatively where bearing surface speeds are not great enough to generate their own hydrodynamic pressure within the bearing, as would be the case for reciprocating pistons. NASA's Astrionics Laboratory, Marshall Space Flight Center, Huntsville, Alabama, granted a prime contract with Mechanical Technology, Inc. to develop squeeze-film gas bearings. The first prototype was fabricated on a subcontract basis by the Bendix Research Laboratories Division of the Bendix Corporation, Southfield, Michigan.

The basic principles involved in a squeeze-film bearing are as follows: The mating surfaces are separated by the vibratory action of an ultrasonic transducer in contact with the bearing; the first few cycles of ultrasonic vibration have the effect of separating the journal from the bearing, thus allowing air to fill the space between them. During the following cycles of ultrasonic vibration the air becomes contained under pressure due to non-linear gaseous flow in the air film at ultrasonic frequencies, thereby creating a net positive load-carrying capability. The load-carrying

capacity is a function of the squeeze number σ and increases with increasing values of the squeeze number:

$$\sigma = \frac{12 \; \Gamma\omega}{P_a} \left(\frac{L}{C}\right)^2$$

where:

P_a = ambient pressure

Γ = viscosity of the gas flow

ω = frequency

L = characteristic length

C = mean clearance

The actual load-carrying capacity can be determined from chart no. 1 when one knows the squeeze number and the excursion ratio, ξ . The excursion ratio is the ratio of the signal amplitude to the mean distance between the mating parts of the bearing. For all practical purposes the load-carrying capacity (per unit area) of the squeeze-film bearing is limited to approximately one-third of the ambient pressure. Power consumption (for the ultrasonic generator) is approximately one watt per pound of load per square inch of transducer face.

Schematic drawings of various squeeze-film designs are shown in Figures 1 through 3. Figure 4 is a photograph of the prototype unit fabricated by the Bendix Research Laboratories, Southfield, MI.

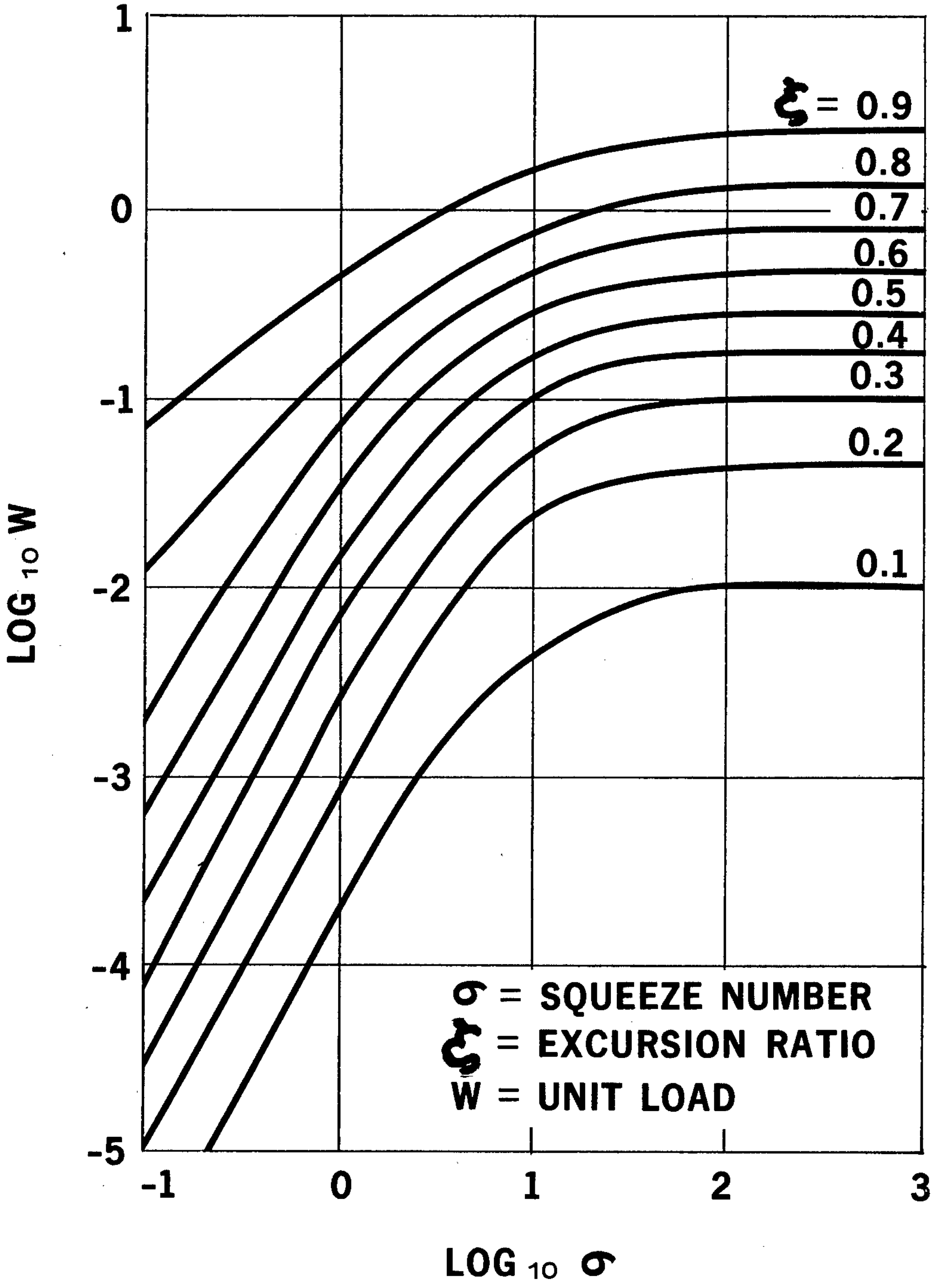
Squeeze-film bearings have been used for damper bearings in turbine engines and for gyroscope bearings. Other uses, such as for bearings in a sensitive chart/pen recorded, have also been reported.

APPROACH AND EQUIPMENT

The major thrust of effort in this work dealt with literature search, patent disclosures, conference attendance and meetings, and discussions with leading workers in the fields of adiabatic engines and squeeze-film bearings. Little effort was spent on hardware or laboratory experimentation since early in this work it was found that this type of activity could justifiably be labled as "reinventing". The state-of-the-art was determined through literature search and conference attendance; problems and requirements were determined from meetings and discussions with vendors and engineers active in the field of ultrasonics, adiabatic engines, and squeeze-film bearings.

CHART I

LOAD CAPACITY OF SQUEEZE BEARINGS



LOAD CARRYING CAPACITY IS FOUND BY KNOWING SQUEEZE NUMBER AND EXCURSION RATIO.

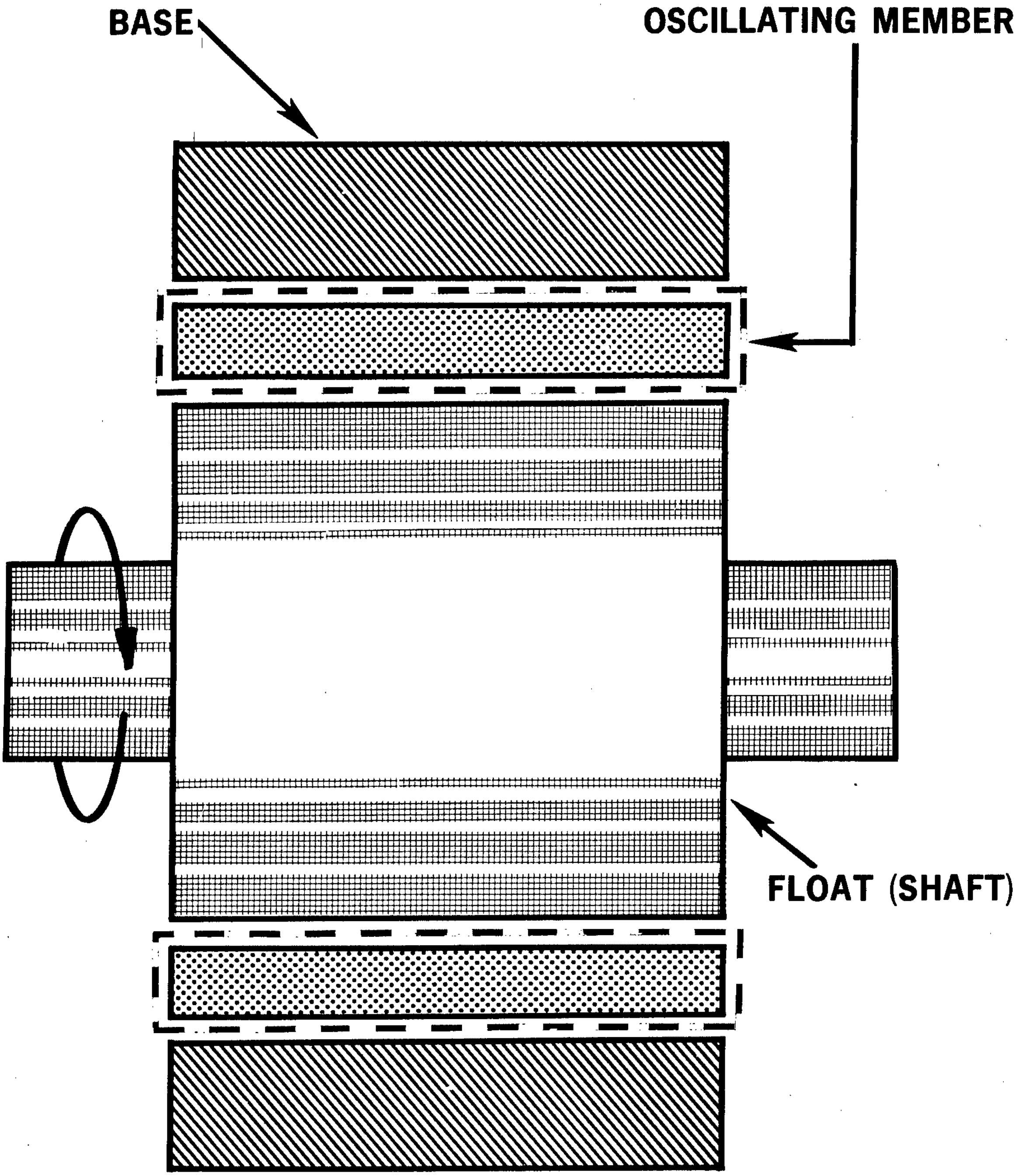


FIG. 1

RADIAL THRUST BEARING USES GAS FILM TO SURROUND OSCILLATING MEMBER.

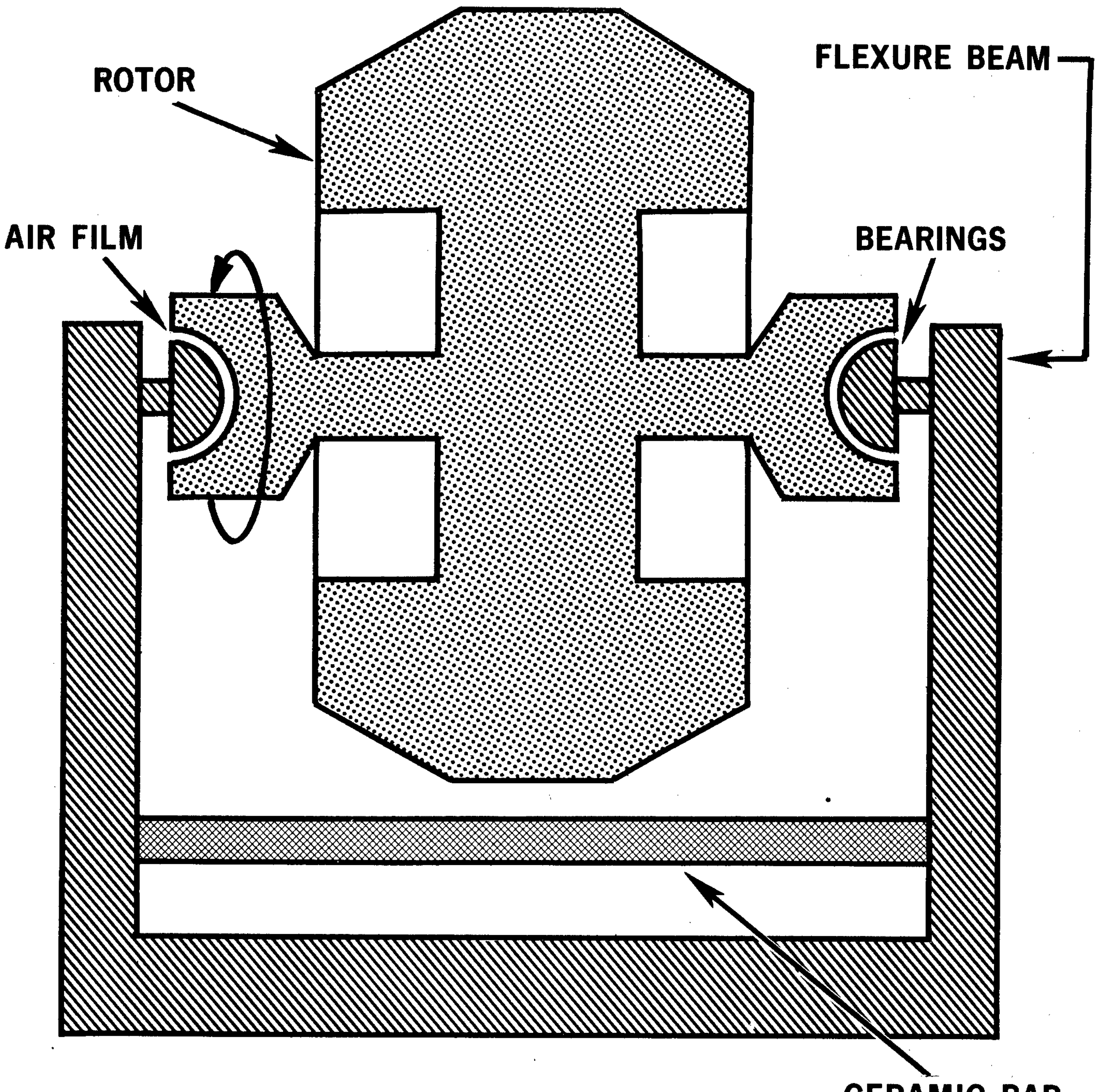


FIG. 2

VIBRATION OF END FLEXURES IS INDUCED BY PIEZOCERAMIC BAR TO CREATE THE AIR FILM.

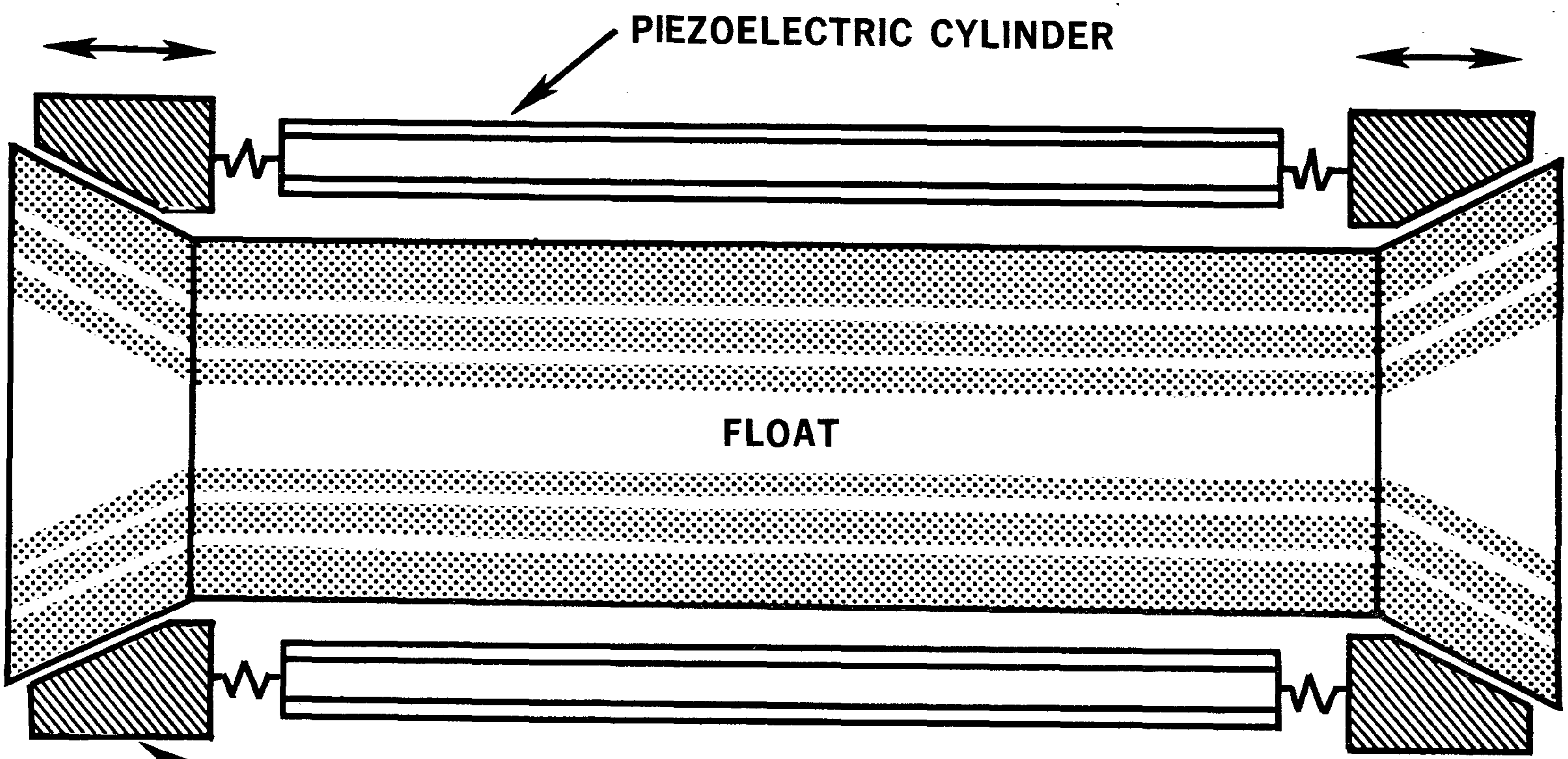


FIG. 3

COMPOSITE TRANSDUCER CONCEPT IS USED TO DESIGN SQUEEZE BEARING SHOWN. HIGH STRENGTH METALS CARRY THE HEAVILY STRESSED PORTIONS OF THE LOAD.

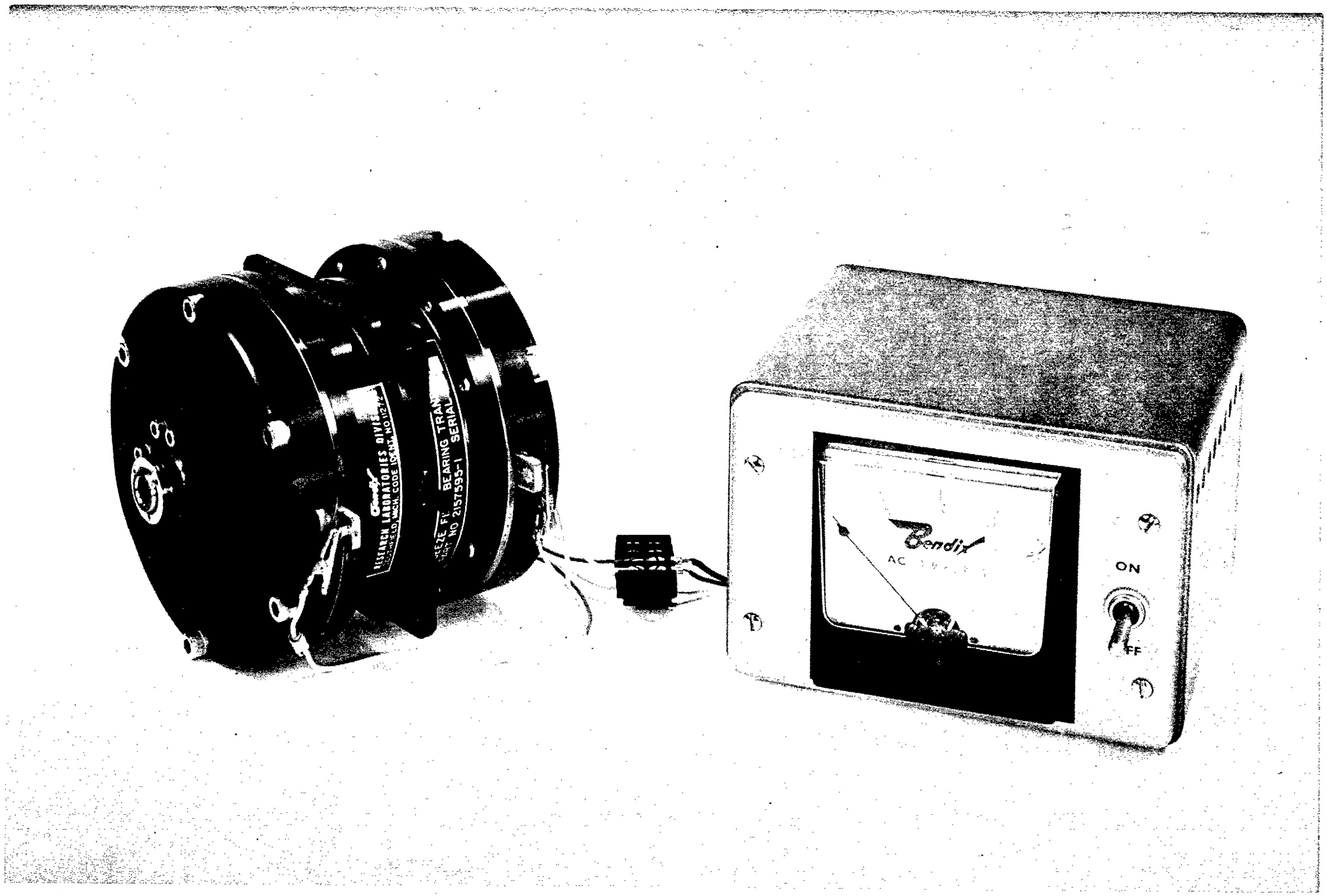


FIG. 4

PHOTOGRAPH OF PROTOTYPE UNIT

RESULTS

It was the intention at the time of proposing this work to design and fabricate a squeeze-film bearing for test purposes. When funding was approved, these activities were programmed via the project task control system on STA Form 4721. These activities were initiated but never completed. The reason for this is that as the literature search progressed, contact was made with both past and present workers in the field; vendors were contacted and meetings and conferences were attended. This type of activity, although not entered on the STA Form 4721, is an important part of any research project and proved to be more germane to this study than equipment design and fabrication activities. Project activities are discussed chronologically as follows:

Mr. B. Teitelbaum, the Bendix Corporation, Southfield, MI, was contacted regarding the squeeze-film bearing model that the Bendix Research Division fabricated for NASA. Mr. Teitelbaum resurrected that model for loan to TARADCOM for demonstration and picture taking purposes. That model utilized a piezoelectric transducer.

Mr. D. Kirk, Branson Sonic Power Company, Troy, MI, was contacted regarding ultrasonic equipment for squeeze-film application. Two different designs of friction pairs or bearings were constructed at TARADCOM and were used for discussion purposes at Branson Sonic Power Company, as examples of the types of bearings desired as squeeze-film bearings. They were not familiar with squeeze-film bearings, but said that they were in a position to sell to us the required ultrasonic equipment, but that they must machine the transducer themselves in order to "tailor it" to their ultrasonic generator. We in turn would furnish the design of the tip or working end of the tip or working end of the transducer/horn. The tip of the transducer/horn in this case, would be one part of the bearing/friction pair. In this case, the transducer would be of the magnetostrictive type rather than piezoelectric type. No further effort was expended in this direction.

Dr. D. F. Wilcox, Mechanical Technology, Incorporated, Latham, NY, was contacted regarding squeeze-film bearings fabricated at MTI. Cost and availability of a demonstration model squeeze-film bearing was discussed. The model was to be an electric motor utilizing squeeze-film bearings rather than conventional bearings; it was to demonstrate an energy savings when utilizing squeeze-film bearings as opposed to using conventional bearings. Dr. Wilcox said that a demonstration model of that type could be designed and built, but that he questioned the value of such a model since conventional air bearings are simpler and are just as good or are even better especially for high speed application. When questioned if that was also true at elevated temperatures, he said yes, that air bearings are presently being used quite adequately in high-speed turbine engines. When he was asked about the possibility of using a squeeze-film bearing to act as a bearing wall for a piston in a reciprocating engine and in particular for a high-temperature engine, such as the

adiabatic engine where conventional lubricants are not applicable, he replied that this was the first he had thought or heard of that suggestion and that he thought that this would be a perfect application of squeeze-film bearing. He was of the opinion that application to pistons made more sense than application to rotary bearings in turbine engines since piston speeds are much slower than speeds normally encountered in turbine bearings. The high turbine speeds lend themselves to use of conventional air bearings, whereas, the slower speeds of pistons do not; the air/gas type squeeze-film bearing would, however, be applicable at piston speeds.

At a later date, Dr. Wilcox informed me that he had discussed this idea with Mr. R. Kamo; Cummins Engine Company, TARADCOM's contractor for the adiabatic engine; and that a serious objection to this idea had surfaced. The objection deals with the load-carrying capability of squeeze-film bearings. The sideway thrust (sometimes referred to as cylinder slap on cylinder walls) in an internal combustion engine is larger than a squeeze-film bearing can be expected to support. This sideway thrust occurs whenever the crank angle is other than at top dead center (TDC) or bottom dead center; it is maximum at 90° before and 90° after TDC since this is where the connecting rod is at its greatest angle relative to the axis of the cylinder and power must be mechanically transmitted to the crankshaft via a connecting rod at this angle. There is no sideway thrust at top dead center or at bottom dead center, and there would be none elsewhere if it were possible to have the connecting rod constrained in such a manner that it never need be angular to piston travel.

Mr. Kamo, Cummins Engine Company, was contacted. He verified his conversation with Dr. Wilcox and said that they are now working on a hydrostatic method of lubrication for the adiabatic engine where the plan is to bleed off some of the combustion gas and use it as a supply for a gas-type bearing. He added that they have funding for this work but would welcome more.

Two patent disclosures have been submitted at TARADCOM on this ILIR project. The intent of the first is merely to put TARADCOM in the legal patent posture in the event this material is patentable. The second specifically addresses the problem of lubrication of the adiabatic engine. It proposes the use of squeeze-film bearing type of lubrication for the adiabatic engine. The objection to this type of lubrication as raised by Dr. Wilcox and Mr. Kamo is overcome by mechanically eliminating sideway thrust. Two such means of doing this are discussed in the second patent disclosure. The first means suggests use of two crankshafts rotating in opposite directions and two connecting rods per piston. This would have the effect of canceling all sideway thrusts because there now are two such sideway thrusts but each would be equal and acting in opposite directions thereby resulting in a zero net sideways thrust. The second method suggests using a pushrod between the piston and the connecting rod. The pushrod is constrained to never being angular to piston travel, thereby eliminating all possibility of sideway thrusts. These two methods are illustrated in Figures 5 and 6.

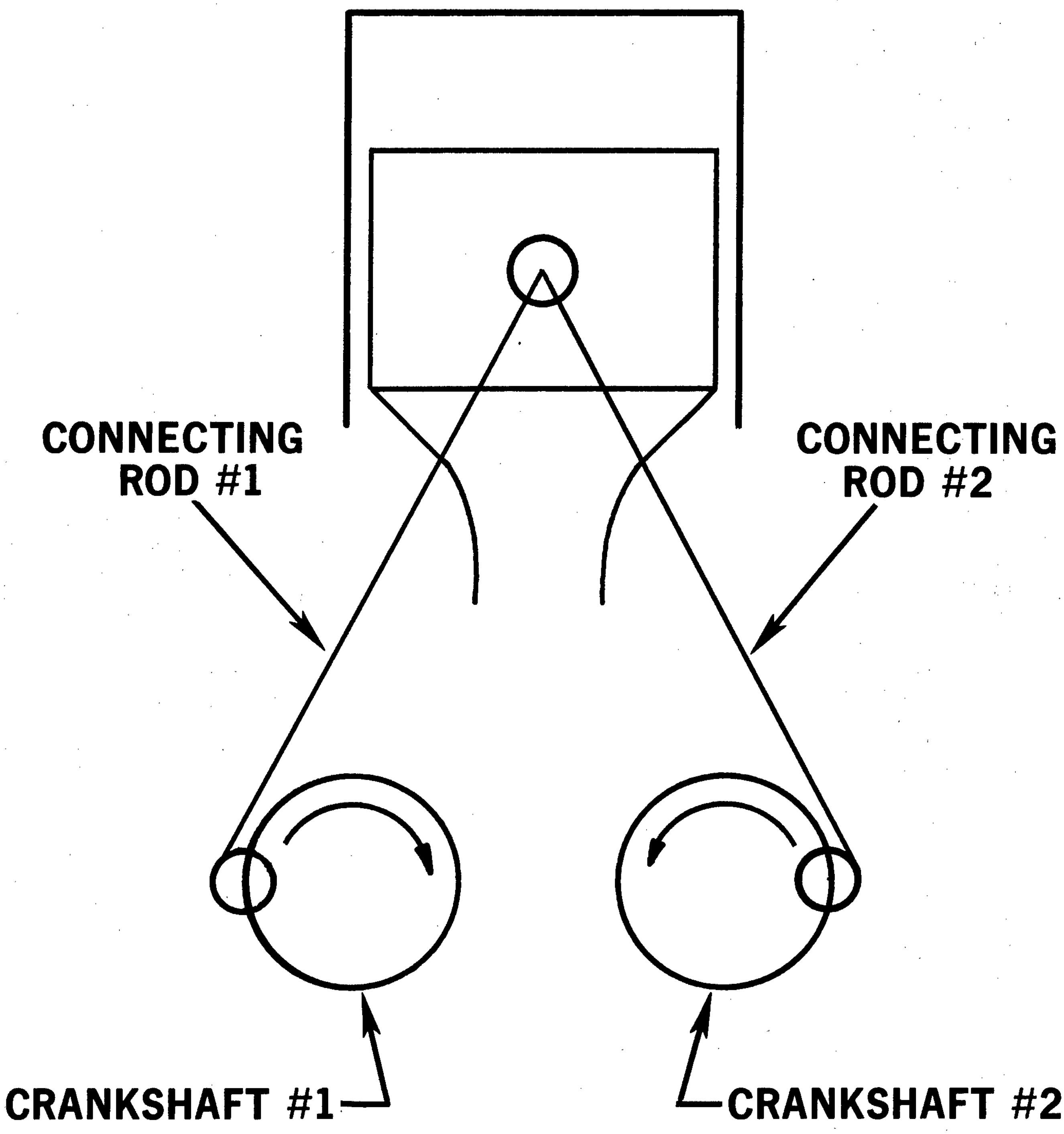


FIG. 5
SCHEMATIC OF ENGINE USING DUAL CRANKSHAFTS AND CONNECTING RODS

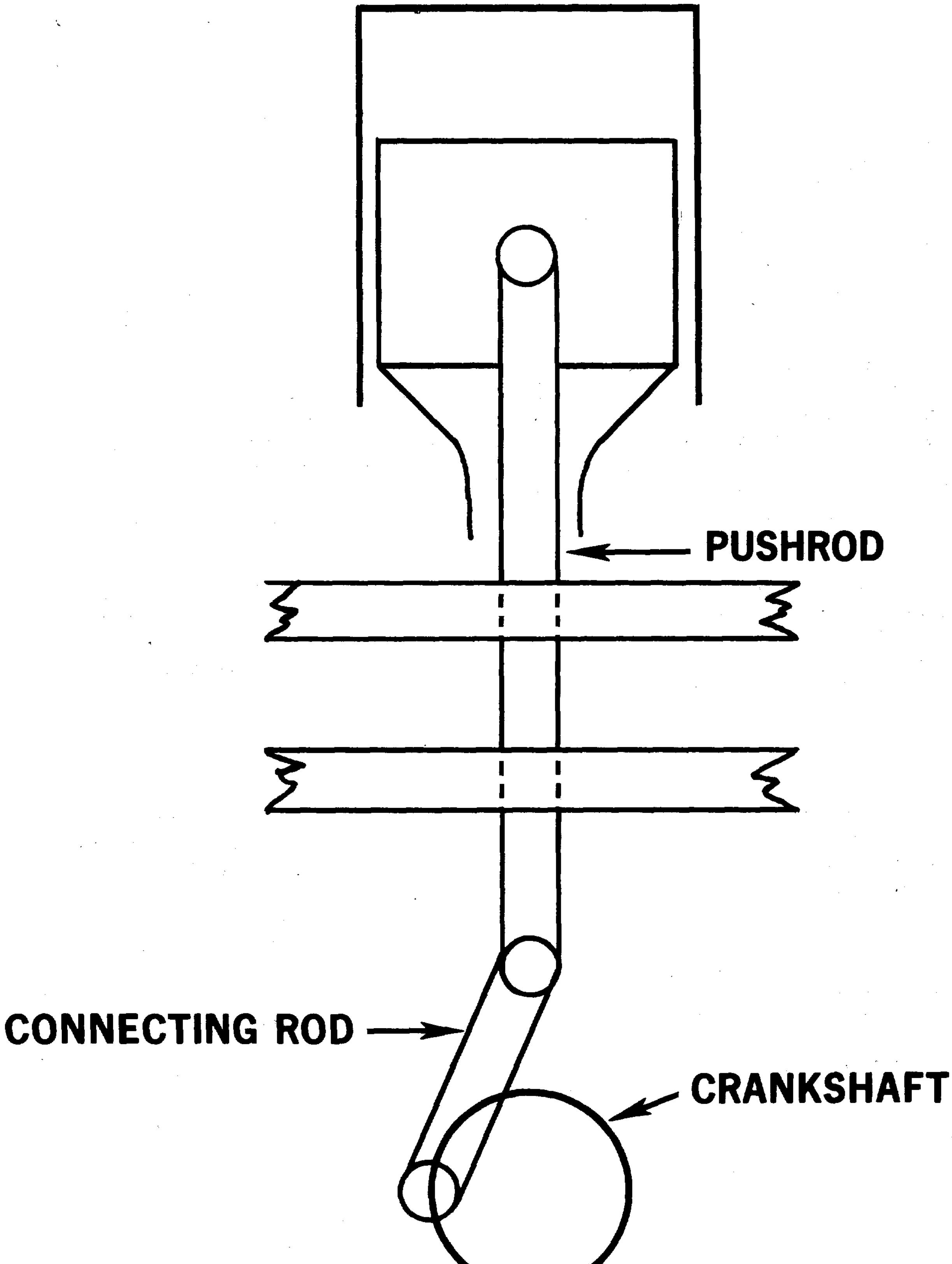


FIG. 6
SCHEMATIC OF ENGINE USING PUSHROD CONCEPT

DISCUSSION

Success or failure of the adiabatic engine project may depend largely on lubrication; without adequate lubrication any engine will fail. Lubrication of the adiabatic engine presents the unique problem of having such a high operating temperature that conventional lubricants fail. The only work in progress at present addressing this problem is the work being done at the Cummins Engine Company where the work is directed at using exhaust gases as a supply of gas for a gas film or bearing between the piston and cylinder walls. Funding for this work is very limited and Cummins Engine Company would welcome additional funding.

Squeeze-film bearings are temperature limited and are not capable of functioning at adiabatic engine operating temperatures with today's materials and today's state of the squeeze-film technology. However, it is felt that presently with the aid of liners in an adiabatic engine, the temperature experienced by a squeeze-film bearing can be lowered to a more favorable temperature for squeeze-film bearing operation. Future materials and future squeeze-film bearing designs may allow operation in adiabatic engines without liners.

The work performed on this ILIR task resulted primarily in a state-of-the-art survey. The survey was concerned with adiabatic engines and squeeze-film bearings. The leaders in both fields were contacted and the possibility of using squeeze-film bearings for lubricating the adiabatic engine was discussed with each.

CONCLUSIONS

This effort resulted in a state-of-the-art survey which essentially has updated TARADCOM's knowledge of squeeze-film bearings and has provided a base from which to negotiate contract work involving squeeze-film bearings in general and in particular as might be applied in the future to the adiabatic engine. Present state-of-the-art of both squeeze-film bearings and adiabatic engines precludes use of the squeeze-film bearing principle for lubrication in the combustion chamber of the adiabatic engine. However, several modifications to the adiabatic engine may make it possible even at the present state-of-the-art and with today's materials.

Other applications of squeeze-film bearings have been reported. As new applications of this technology are reported, design engineers at TARCOM/TARADCOM are urged to make use of this technology for application to tank-automotive vehicles.

RECOMMENDATIONS

Further work is required before the squeeze-film bearing concept can be utilized in the combustion chamber of the adiabatic engine even with design changes recommended in this report. It is felt, however, that

this type work is not ILIR category work, but that it is work that should be done by established leaders in these two fields. Recommended contractors for this work would be the Cummins Engine Company for adiabatic engine work and Mechanical Technology Inc., for the squeeze-film work. Contracting would require that the two companies work jointly on the project.

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This effort has resulted in a state-of-the-art survey. It involved literature search, conference attendance and meeting with workers and leaders in the fields of ultrasonic lubrication and adiabatic engines. Because of the infancy of both of these fields it appears premature at this time to try to utilize ultrasonic lubrication in the combustion chamber of the adiabatic engine. However, this work includes two suggested adiabatic engine design changes which may be employed presently if the need for ultrasonic lubrication of the combustion chamber of the adiabatic engine becomes sufficiently urgent.

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